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Design and Testing of a Mobile Studio Operational Amplifier Trainer Board

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Abstract: **This study involves the design and testing of a trainer board that can enable electronic engineering students to learn the basics and applications of Operational Amplifiers as a means of supplementing their technical know-how of on how these devices are actually used in the field. The trainer board was computer-interfaced with a mobile studio--the Rensselaer- Mobile Studio and its measurement capability was tested with series of correlation and comparison test set-up with regular multimeters to prove that the Rensselaer Mobile Studio can be successfully interfaced with an Operational Amplifier Trainer Board.**

Keywords: **Mobile Studio, Operational Amplifiers, Trainer Board, Op-Amps, Rensselaer Mobile studio.**

1. INTRODUCTION

Operational Amplifiers or *Op-Amps* are one of the most needed and most successful components in the electronic communication industry. It is a transistorized circuit that mainly functions as amplifiers. This device can found in computer chips, industrial machines and even military equipment functioning as the core of the semiconductor device. It is imperative for anyone who aspires to become an electronics engineer to have sufficient knowledge of Op-Amps, especially in the field of semiconductor electronics. Manuel Toledo (2008) an Engineer of UPRM, described the operational amplifier as *perhaps the most important building block for the design of analog circuits.* This is included in his article *Basic Op-Amp Circuits* (August 13, 2008).which is submitted in instrumentation. He is also quoted as saying that "*Good Knowledge of the Op-Amp characteristics and application is essential for a successful analog engineer".* This can be done through theoretical training and frequent exposure to its applications.

Training modules have arisen hand in hand with innovations in laboratory teaching especially in electronics laboratories for they offer actual simulations of the topic being discussed, enabling the students to safely explore their curiosity with these devices. Even universities with advanced laboratory equipment possess these types of modular learning devices. In a study by Nina Katajavuori et. al (2006), *The significance of practical training in linking theoretical studies with practice,* Nina designed a setup of hands-on training for them, and as result, more students felt a more complete understanding of the topic.

Notwithstanding the fact that Op-Amps are the most basic electronic circuit, the teaching of the topic of Op-Amps seems to have been left behind when it comes to modular training. Op-Amps are mostly taught in schools as a mathematical problem that needs solution through computations. From an experienced engineer's view, Op-Amps have been given different levels of importance when it comes to circuit applications. For chapter 13 of the classic electronics textbook, Electronics Devices and Circuit Theory (3rd Edition), by Boylestad and Nashelsky, *"Linear ICs; Operational Amplifiers",* The Operational Amplifier is described as an essential state? the circuit in everyday electronics. It is an electronics topic that must be given much attention during the starting years in B.S. Electronics Engineering.

2. BACKGROUND OF THE STUDY

Nowadays, training boards have become essential in practical learning in the field of electronics. Since electronics is taught through different topics describing different devices, variations within these training modules occur. Within the most important subjects in electronics, the use of Op-Amps have arisen due to their flexibility in different applications. What is bothersome, however, is the idea that students seem to treat Op-Amps as just a giveaway lesson since it is a solved-type problem. In addition, students treat Op-Amp as just a simple amplifier due to lack of proper knowledge and appreciation of this device. Since the Operational Amplifier training module is not available in the Lyceum of the Philippines University – Cavite (LPU-Cavite), the creation of such a module would be very beneficial to electronics engineering students in LPU-Cavite. It is this for reason that the authors thought of designing and testing a training board that would enable the students to experience hands-on applications of Op-Amps and to appreciate the importance of this device in the field of electronic engineering. This training module would not only guide the electronics student to the connections of the circuit proper but also, to the analysis of each circuit. Since the knowledge of how to use Op-Amps is crucial to the training of electronics engineering students, having a trainer on how to use and implement this device would be very useful and helpful and efficient in an electronics engineering laboratory.

In addition to that, the Analog Devices Inc. in General Trias had recently donated a mobile studio named Rensselaer Mobile Studio to LPU- Cavite as part of their linkage program in imparting knowledge among universities about semiconductor devices. It was fortuitous that the said mobile studio would form part of the Mobile Studio Operational Amplifier Trainer Module.

Through this modular training equipment, the authors sought to pioneer the development of a training module that would explain Op-Amps in an application--based approach enabling students to learn the applications through hands-on experience while following the theoretical topics given in the textbooks. The Training Module would serve as their guideline not only in the operation of the device but also in the lesson about Op-Amps. While appearing to be simple as it is portrayed here, the Training module would hopefully inspire development of future training equipment to promote the learning of operational amplifiers. Measurements would be guided by a trusted and reliable laboratory device--the Rensselaer Mobile Studio device offered by Analog Devices Inc. to their academic partners. The training module would be a jam-pack computer interfaced training device that would simulate the Operational Amplifier lessons and circuit applications. Moreover, the Op-Amp training module would have the advantage that it could be flexibly manipulated through pin to pin assignment of component values a user could incorporate to the circuit.

The electronic components of the training board would be attached to the board itself, leaving traces for the users to follow. The integration of the board would resemble the famous *De Lorenzo training module*. There would be pins presented in a distinct location on the circuits that would serve as the Test Points for the users in case those measurements were needed. Moreover, the whole training board of Op-Amps would depict the different circuitry uses of the Op-Amps, how it is used and especially why the circuit is created. To support the measuring circuitry, the Op-Amps trainer would have its own measuring meters, the Rensselaer Mobile Studio Desktop, making it easier to use without requiring any extended network of multimeters as much as possible, particularly with the use of oscilloscope. It would be advantageous in the Philippine setting since it would run with the rated AC voltage supply in the Philippines with the frequency of a common establishment. Moreover, the module file be produced would be interfaced with everything on the hardware trainer. It would serve as the lesson guide to the student using the trainer on how they would acquire the information it offers.

Regarding the training module, it will come with a step by step procedure just like the De Lorenzo modules. The highlight of the Op-Amp trainer module is the use of the Rensselaer Mobile Studio which is an innovation over with the training technology offered by Analog Devices Inc. It is a jam–pack training equipment, with a computer interfacing style that's absolutely equal to the LPU's current training module. The module that would be developed by the researchers will promote the computer interfacing of the Op-Amp training module. It would cover specific lessons and basics of Op-Amp circuitry that is essential for the starters. Flexibility of the circuit would be based on its available values selection presented on the board itself. A user can freely design the characteristic of his circuit by changing the values of some parts of the circuit based on the predefined set of values that is prescribed in the Op-Amp Trainer Module Manual. It would then be a pioneering training module that would hopefully lead to the development of better training modules in the future. The circuit board itself would be fixed, for the power supplies and the intermediate components were packed together as plug and play device.

Finally, the Op-Amp's flexibility can hopefully induce technical minds to create in potentially innovative circuits. This will therefore, serve as foundation for producing well-trained innovative electronic engineering students who can confidently apply their knowledge when it comes to field demonstration.

Statement of the Problem:

The research problem that the authors sought to address was the following: Would it be possible to design a Mobile Studio Training Board interfaced with Rensselaer Mobile Studio that would enable electronic engineering students to learn the basics of operational amplifiers and to have a hand-on experience with the applications of Op-Amps computer-interfaced with a Rensselaer Mobile Studio as the measuring device.

Objective of the Study:

The main objective of the study was to design, construct and test a Trainer Board that would teach the basic concepts of Operational Amplifier circuit that utilizing the Rensselaer Mobile Studio. In particular the research, attempted to achieve the following specific objectives.

1. To answer the requirements of Software and Hardware design by performing aspects such as: Design a circuit board that will be full of Operational Amplifier Circuit, strategically chosen to sustain step-by-step learning through hands-on activities. The circuit board's circuitry is composed of Open Loop Gain, Closed Loop Gain, Inverting Amplifier, Non-inverting Amplifier, Comparator and Grounding Systems, Summing Amplifier, Instrumentation Amplifier, Differentiator, Integrator and Relaxation Oscillator/ Square Wave Generator;

2. To design a safe and versatile Frame that will be the main station for the circuit board. It must have power supply along with the needed connection as it will be interfaced on the board;

3. To create and design a module, which is computer interfaced and program-based. This module will be a software-type and will be used along with the computer. The interface between the computer and the hardware is the Rensselaer Mobile Studio; and

4. To Test the accuracy and reliability of the Rensselaer Mobile Studio's measuring capability. The result would have to undergo different correlation tests to establish sensitivity and reliability of the measuring device. Correlation is one of the biggest factors to be considered in electronics industry.

3. REVIEW OF PREVIOUS STUDIES

Op-Amp applications have been increasing hand in hand with the nano-technology. In the article-study of an Analog Devices Engineer, James Wong (Archives of Analog Devices Incorporated), *A Collection of Amp Applications* [11], he investigated the possible applications of the Operational Amplifiers. He listed 38 applications and included all the possible circuitry on each one. Each circuit also was possible and usable. Hence, it proves the importance of Operational Amplifier since it created so much application for a single device.

Another application of Operational Amplifier, which is the inverting and non-inverting amplifiers with feedback, played a great role in analog circuit. In a study for Operational Amplifier by Aloke Raj Sarkar, *Linearization of NTC Thermistor Characteristic using Op-Amp Based Inverting Amplifier* (2012), studies the use of an Inverting Amplifier as a circuit for linearization of NTC Thermistor characteristics [9]. He concluded in his own experimental paradigm that the Operational Amplifiers have been a very big help in improving the linearity of the thermistor. Other than that, the gain becomes more sensitive in a way that it becomes linear in behavior. It is a complete reasoning factor why the Inverting and Non-Inverting Amplifier are essential building blocks of the Analog Devices.

L. Richard Carley of Carnegie Mellon University, Pittsburgh Pennsylvania, investigated the automation of designing amplifiers including the Operational Amplifiers. His study, *Automated Design of Operational Amplifiers: A Case Study* (1990) uses the fact that Civil Engineers forge their designs in a Computer Aided Drafting (CAD) [5]. He tries to build sole software for designing circuits for deeper analysis, just like the Multisim, but the catch is that it can generate a logical circuit based on the device's properties. He believes that integration of so many devices in the Integrated Circuit can be done by the computer. The result is non-high profile software that can somehow "analyze" the device and will create its own. With accordance to this, he attests that the Analog devices such as Operational Amplifiers are so important to integrate so the interest on this device should be prioritized.

In Signal generation designs, a study of AkmSydulHaque (2008) of The University of Texas emphasized the use of Operational Amplifiers as Signal Generator. His study *Design of a Signal Generator Using Current Feedback Operational Amplifiers* works on a current feedback based Operational Amplifiers and the exhibition of these devices. He emphasized the efficiency of a current-based feedback compared to voltage-based feedback in producing a signal generator. Signal generator is a basic circuit that an Operational Amplifier handles. He demonstrated the filtering of the produced outputs with the use of Operational Amplifier itself. Versatility was proved since his products are all tunable circuitry, meaning it can be changes in a range. This study inserted the *Square Wave Generator* in one of the circuit application of Operational Amplifier Mobile Studio.

One of the key circuits in the Operational Amplifier mobile studio is the Rensselaer Mobile Studio component that will be used for measuring parameters. A thesis study of Matthew Philip Wilson (December 2008) entitled *Mobile Studio's Wireless Expansion: a low-cost, wireless toolset for expanding Mobile Studio's instrumentation suite* encompass the use of the very own Rensselaer Mobile Studio. It is a thesis created at the Rensselaer Polytechnic Institute who owns the Mobile Studio. He uses the Mobile studio in different type of circuit and matched the results through correlation test. It has been found out that the Mobile studio is a reliable and trustworthy digital meter. It added reliability to the Rensselaer to be chosen as one of the interface the Operational Amplifier thesis by the researchers.

From aforementioned previous studies, the researchers became confident that Operational Amplifier could be made an interesting subject for electronic engineering students.

As for the Rensselaer Mobile Studio to be used as the main measurement device of the trainer board, it is tested in different applications to prove its consistency with the measurement. Since Operational Amplifiers are common to electronic devices, the Rensselaer's versatility would also be tested. For the researchers, the need of the measurement capability in terms of voltage and current would be needed.

4. ASSEMBLY OF THE TRAINER BOARD

The assembly of the Operational Amplifier Trainer board follows basic principle of integrating the circuitry to the board. This will serve as the basis in constructing and designing the circuit. In Figure 1, The Operational Amplifier Trainer Module – Process Flow Design flow chart describes the way of operation involved in the Trainer Module.

The whole setup can be explained in terms of the manner of selection of circuit, opening the software module, interfacing the Rensselaer Mobile Studio, integrating the Supply and determining the values. These basic steps are the outline in which the device will work-out every time it is utilized, by determining the processes involved in the operation, the manner of selection of circuit, opening the software module, interfacing the Rensselaer Mobile Studio, Integrating the Supply and determining the values.. The control system of the Trainer is shown on the Figure 2: Operational Amplifier Trainer Module Control System Model.

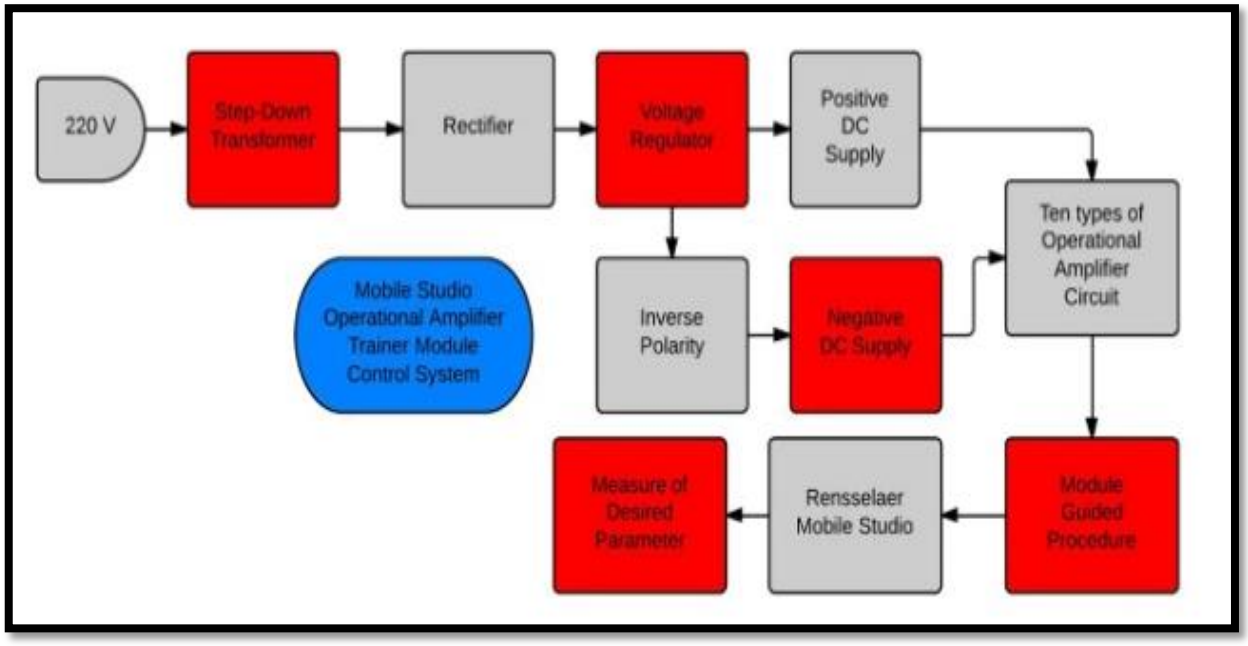

Figure 1 Process Flow Design Flow Chart for the Op-Amp trainer Module

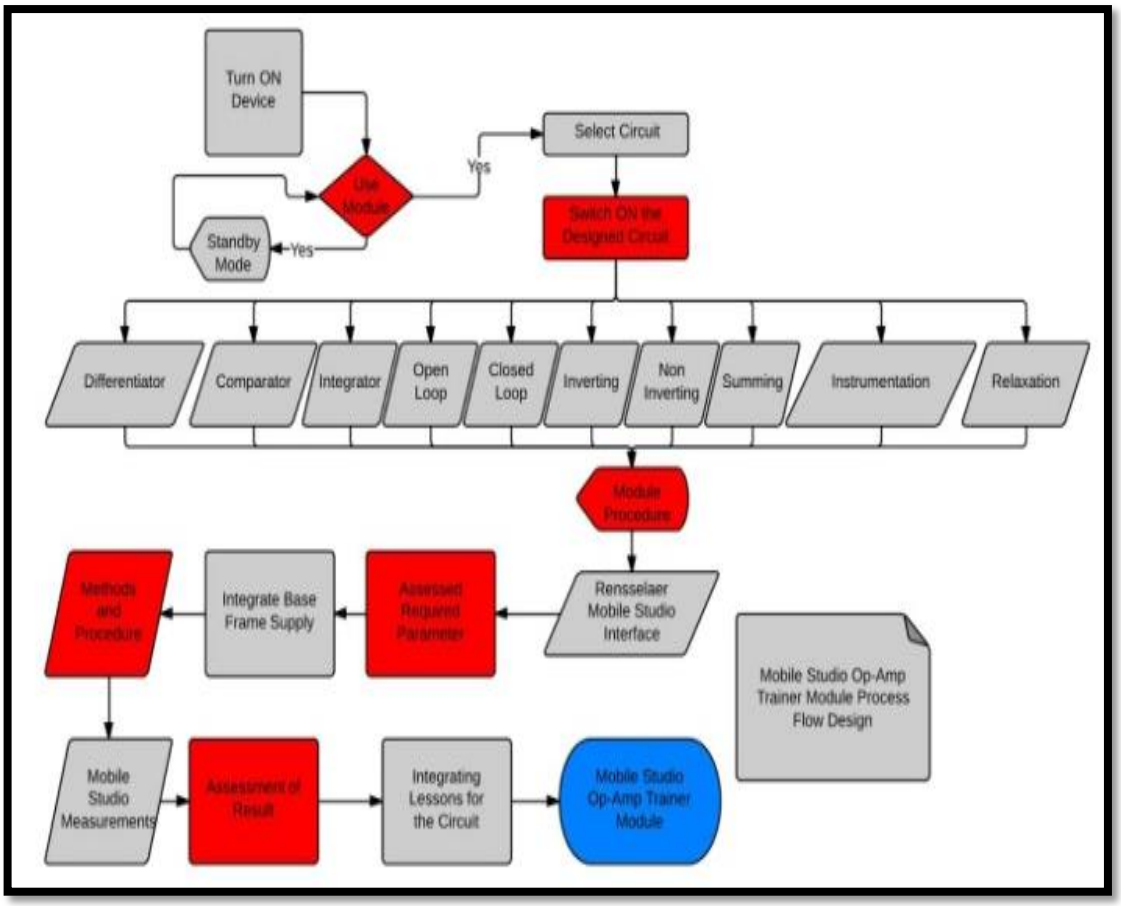

Figure 2 Operational AMPLIFIER Trainer Module Control System

Figure 2 describes the way of controlling the device. As for the main input of operation, there will be a 240v-60Hz supply that will come from the common AC plugs in laboratory. It will be the setup of power supply to the whole base frame and the circuit. Power inputs are created and separated to positive and negative supply through inversing the polarity of the supply. Positive and Negative Supply were needed in the simulation of the circuits in the trainer module. Thereafter, selection of circuit can proceed.

Ten of the basic Operational Amplifiers were chosen from the arsenal of premiere electronic textbooks. Some of them were chosen with the basis from an article entitled *Basic Op-Amp Circuits* by Manuel Toledo. These circuits were substantial to the needs of learning of students in their industrial life after college. After the selection of the circuit (circuit may depend on your preferred lesson), the modular guide software proceeded. The user will follow certain procedures and methods regarding the chosen circuit.

After the setting up of needed parameters, then the interfacing of the Rensselaer is needed. Rensselaer is a Mobile Studio device mainly used for computer interfaced measurement. It is a versatile device capable of both supplying and measuring certain outputs. Thereafter, the Operational Amplifier Trainer Module with computer interfaced program was described.

5. RESULTS OF TESTING AND EVALUATION

1. Reliability Test for Rensselaer:

Reliability Testing are consist of different testing for the measurement capability of the Rensselaer Mobile Studio. A series of test setups will be done, performing the measurement Voltage. This setup procedure will be created by the researchers in a repetitive order, and analysis of preciseness will take place after. This will determine the reliability of the Rensselaer.

Voltage Measurement Reliability Testing:

Positive Voltage - The setup consisted of a known or fixed voltage source which is a 7810 IC regulator which is a constant source for a positive 10V supply. It will be the main reference for the measurement to be done by the three

different Testers. The result's aim will be the reliability of the Rensselaer Mobile Studio in handling measurement of a known value.

Negative Voltage - The setup is consist of a known or fixed voltage source which is a 7910 IC regulator which is a constant source for a negative 10V supply. It will be the main reference for the measurement to be done by the three different Testers. The result's aim will be the reliability of the Rensselaer Mobile Studio in handling measurement of a known value. It is the negative variant of the previous test, and which will define the capability of the Mobile Studio to perform voltage measurement in negative values.

Gross Leakage Test-Gross Leakage Test is a test intended to measure the output voltage of the Source Voltage. The power supply to be used on the Mobile Studio Trainer can be varied to different voltage levels compensating different circuit needs. In testing the source voltage, the output voltage will be measured and compared to the expected value required for the circuit.

Continuity Test-Each Branch-node connection on the circuits included in the Mobile Studio was measured for proper connection. Before the actual usage of the circuits, connections were checked if the circuit is properly performing its assigned function. It is also to ensure that the components present in the circuit conducts, excluding some of special ICs (Operational Amplifier) in which needs supply to constitute input-output connection.

After trials on the circuit board, continuity between the copper traces was determined. It was performed using the continuity function of the Fluke Multimeter. It shows that there are minimal mistakes with the first trial on the continuity of the copper traces, before employing the circuitry, the researchers managed to place connecting wires to compensate for the imperfections of the board.

Module Program Test-It is a kind of test that is a standard operating procedure in creating software. It is a manual checking of all the simulations and computations included in the program. The program may cause bugs and error if a single code fails to be written properly. The module, first and foremost, is the main calculation medium that will be used while conducting the experiment. The user or the student will input their set of values on the Graphic Interface presented on the Module. In conducting the test, there will be a comparison on the computed output of the program and the Calculator and the Mobile Studio at a given Set up.

Functionality Test-This test determines the functionality of each circuit based on the theoretical basis from research materials. It will set a circuit on a given set up in which will determine logically the capability of the circuit to give certain output with the basis on the real-life values.

Table 1 Functionality Test Results

Circuits with computation program	Output Voltage calculation using Casio F991ES+ (Calculator in-test)	Output Voltage measured in the Trainer board at a given setup	Percentage Error Presented
Open Loop Gain	9V (rail)	9.0304 V	0.34%
Closed Loop Gain	3.9054 V	3.9056 V	5.12×10^{-3} %
Inverting Amplifier	-3.6V	-3.7385V	3.847%
Relaxation Oscillator	Square Wave Output	Square Wave Output	N/A
Non-Inverting Amplifier	6.312V	6.3981V	1.36%
Comparator	Square Output (designed)	Square Output	N/A
Summing Amplifier	-4.3658V	-4.4181V	1.1979%
Integrator	Square to Triangle Sine to Cosine	Triangle Cosine	**N/A**
Differentiator	Square to Spike Triangle to Square Sine to Cosine	Spike Square Cosine	**N/A**
Instrumentation Amplifier	5.23V	5.298V	1.3%

6. SUMMARY, CONCLUSION AND RECOMMENDATION

Summary:

The study entitled ***"Mobile Studio Op-Amp Trainer Module"*** showcases the enhancement of the electronics trainer board in terms of imposing Operational Amplifiers lesson. Trainer board's common parts such as the power supply and the supply pins were still constant, with changes on the lesson proper which is the integrating of Operational Amplifier. The study aims to create a Trainer Board that will tackle the lessons of the Operational Amplifier which is one of the most needed lessons in semiconductor Industry.

The circuit proper is composed of a Power Supply, Trainer Board Dock Frame and The Operational Amplifier Board. The power supply circuit was designed by the researchers to meet the requirements of the Operational Amplifiers in terms of supply capability and variability. The main factors of the Trainer circuit are (a) circuit construction, (b) circuit output's accuracy, (c) circuit output's precision and (d) the Rensselaer Mobile Studio's measurement accuracy. The circuit was constructed with the circuit construction based on an Electronics textbook, with accuracy tested using series of setup, output's precision with correlation tests and accuracy of the Mobile Studio through different probing tests.

Prior to the testing of the Mobile Studio and the components involved, the Mobile Studio Op-Amp trainer was completed. There was an accompanying module program to be used by the student to guide them in the operation of the trainer board. The circuit board was composed of the basic applications of the Operational Amplifier that are important in a semiconductor industry. It will use a +/- 10V rail voltage as the main supply of the circuit, supplied by the regulated output of the power supply. The circuit was tested using the researchers' designed setup based on the setup of the previous researcher? Each of which passed certain functionality test that made them eligible for use.

With regard to the safety of the device, the circuit board was engaged with measuring any extraneous voltage on the board. It shows that there is no lateral current flowing on the board since the power supply circuit is barely separated from the circuit board.

The final output of the Mobile Studio Op-Amp Trainer is a package of circuit board consisting of the power supply and the circuit that has the operational amplifier embedded on it. The device was tested with the series of test setup that determined its functionality of the circuit, accuracy of the output and the precision of the circuit's output.

Conclusion:

From the results of the test setup, the different Operational-amplifier circuitry embedded on the trainer board functioned as expected on the basis of the theory of its operations. The bases for the theory of the circuits are the basic electronics books used in college such as *"Electronic Devices and Circuit Theory by Robert L. Boylestad and Louis Nashelsky" and "Operational Amplifiers and Linear Integrated Circuits by Robert F. Coughlin and Frederick F. Driscoll"* which are two of the most reliable references source for electronics devices. It can be concluded that the circuits performed the operations on each application. The feasibility of the application was also verified through functionality test made on the testing processes.

Using the Rensselaer Mobile Studio, the measurement done on each of the circuit's output in comparison with the other reliable measuring device proves that the mobile studio can measure any measurement accurately. Though, there is a flaw with the measurement capability of the Mobile Studio, which includes engaging with the high impedance measurement. this is noted in the recommendation below, that the mobile studio is affected by the measurement that exceeds 6Kohms of relative impedance.

The Mobile Studio Op-Amp trainer is a reliable training device based on the series of test done. With regards to the functionality test applied, the trainer is verified to perform the basic lessons included on the module of basic applications. For safety, the circuit of the power supply is purposely separated with the circuit board to avoid extraneous currents flowing on the nodes. Overall, the Mobile Studio Operational Amplifier is 100% reliable in terms of functionality, accuracy and precision.

Recommendations:

For the flaws found during the research proper, the researchers are open to any suggestion for improvement of the trainer board. Rensselaer Mobile Studio's possibility is unlimited to any circuit application that requires measurement of small amount of voltages. For modification of the circuit, the researchers recommend innovation on the application of the

circuits. Any circuit can be utilized for the module. The power supply of the trainer was left with the high range of voltages for future application. The design of the power supply was versatile enough to supply exact voltages through the hanging values of the regulators.

Though there is a limit to the measurement capability of the Rensselaer Mobile Studio that is significant with which is the measurement of the high impedances and measuring large voltages. The Rensselaer is limited to +/- 10 V so further improvement on application should only require the said limitation. The input impedance should not exceed any higher than 6kΩ rated resistance to maintain accuracy with the measurement. Any circuit measurements within these limits were part of the recommended advancement for the trainer board.

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